Chapter 3
RISK

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) addresses the health and environmental hazards, exposures, and risks that may result from using a making holes conductive (MHC) technology. The information presented here focuses entirely on MHC technologies. It does not, nor is it intended to, represent the full range of hazards or risks that could be associated with printed wiring board (PWB) manufacturing.

Section 3.1 identifies possible sources of environmental releases from MHC manufacturing and, in some cases, discusses the nature and quantity of those releases. Section 3.2 assesses occupational and general population (i.e., the public living near a PWB facility; fish in streams that receive wastewater from PWB facilities) exposures to MHC chemicals. This section quantitatively estimates inhalation and dermal exposure to workers and inhalation exposure to the public living near a PWB facility. Section 3.3 presents human health hazard and aquatic toxicity data for MHC chemicals. Section 3.4 characterizes the risks and concerns associated with the exposures estimated in Section 3.2. In all of these sections, the methodologies or models used to estimate releases, exposures, or risks are described along with the associated assumptions and uncertainties. In order to protect the identity of the proprietary chemicals, the chemical concentrations, exposures, and toxicological data for these chemicals are not given in the report. However, those proprietary chemicals that may present a potential risk to human health are identified by their generic chemical name in Section 3.4. Section 3.5 summarizes chemical safety hazards from material safety data sheets (MSDSs) for MHC chemical products and discusses process safety issues.

3.1 SOURCE RELEASE ASSESSMENT

This section of the CTSA uses data from the IPC Workplace Practices Questionnaire, together with other data sources, to identify sources and amounts of environmental releases. Both on-site releases (e.g., evaporative or fugitive emissions from the process, etc.) and off-site transfers (e.g., discharges to publicly-owned treatment works [POTWs]) are identified and, if sufficient data exist, characterized. The objectives of the Source Release Assessment are to:

- Identify potential sources of releases.
- Characterize the source conditions surrounding the releases, such as a heated bath or the presence of local ventilation.
- Where possible, characterize the nature and quantity of releases under the source conditions.

Many of these releases may be mitigated and even prevented through pollution prevention techniques and good operating procedures at some PWB facilities. However, they are included in this assessment to illustrate the range of releases that may occur from MHC processes.

A material balance approach was used to identify and characterize environmental releases associated with day-to-day operation of MHC processes. Modeling of air releases that could not be explicitly estimated from the data is done in the Exposure Assessment (See Section 3.2).

Section 3.1.1 describes the data sources and assumptions used in the Source Release Assessment. Section 3.1.2 discusses the material balance approach used and release information and data pertaining to all MHC process alternatives. Section 3.1.3 presents source and release information and data for specific MHC process alternatives. Section 3.1.4 discusses uncertainties in the Source Release Assessment.

3.1.1 Data Sources and Assumptions

This section presents a general discussion of data sources and assumptions for the Source Release Assessment. More detailed information is presented for specific inputs and releases in Sections 3.1.2 and 3.1.3.

Sources of data used in the Source Release Assessment include:

- IPC Workplace Practices Questionnaire and Performance Demonstration data (see Appendix A, Data Collection Sheets).
- Supplier-provided data, including publicly-available bath chemistry data and supplier Product Data Sheets describing how to mix and maintain baths (see Appendix B, Publicly-Available Bath Chemistry Data).
- Engineering estimates.
- The DfE PWB Project publication, *Printed Wiring Board Pollution Prevention and Control: Analysis of Survey Results* (EPA, 1995a).

Bath chemistry data were collected in the IPC Workplace Practices Questionnaire, but these data were not used due to inconsistencies in responses to the questions pertaining to bath chemistry. Instead, MHC chemical suppliers participating in the Performance Demonstration each submitted publicly-available data on their respective product lines; estimated bath concentration ranges were determined based on this information. The use of publicly-available bath chemistry data is discussed in detail in Section 2.1.4.

Several assumptions or adjustments were made to put the IPC Workplace Practices Questionnaire data in a consistent form for all MHC technologies. These include the following:

- To convert data reported on a per day basis to an annual basis, the number of days per year reported for questionnaire question 1.1 was used. For data on a weekly or monthly basis, 12 months per year and 50 weeks per year were assumed.
- If data were reported on a per shift basis, the number of shifts per day (from questionnaire question 1.4) was used to convert to a per day basis.
- Bath names in the questionnaire database were revised to be consistent with the generic MHC process descriptions in Section 2.1.3.

To facilitate comparison among process alternatives and to adjust for the wide variations in the data due to differing size of PWB facilities, questionnaire data are presented here both as reported in the questionnaires (usually as an annual quantity consumed or produced), and normalized by annual surface square feet (ssf) of PWB produced. Normalizing the data, however, may not fully account for possible differences in processing methods that could result from higher production levels.

3.1.2 Overall Material Balance for MHC Technologies

A general material balance is presented here to identify and characterize inputs to and potential releases from the MHC process alternatives. Due to limitations and gaps in the available data, no attempt is made to perform a quantitative balance of inputs and outputs. This approach is still useful, however, as an organizing tool for discussing the various inputs to and outputs from MHC processes and presenting the available data. Figure 3.1 depicts inputs to a generalized MHC process line, along with possible outputs, including PWB product, solid waste, air emissions, and wastewater discharges. Many PWB manufacturers have an on-site wastewater treatment system for pretreating wastewaters prior to direct discharge to a stream or lake or indirect discharge to a POTW. Figure 3.2 describes a simplified PWB wastewater treatment system, including the inputs and outputs of interest in the Source Release Assessment.

<u>Inputs</u>

Possible inputs to an MHC process line include bath chemicals, copper-clad PWBs that have been processed through previous PWB manufacturing process steps, water, and cleaning chemicals. These inputs are described below.

I_1 *Bath chemicals used.* This includes chemical formulations used for initial bath make-up, bath additions, and bath replacement. Bath formulations and the chemical constituents of those formulations were characterized based on publicly-available bath chemistry data and some proprietary bath chemistry data (see Section 2.1.4 and Appendix B). PWB manufacturers were asked to report the quantity of MHC chemicals they use annually in the IPC Workplace Practices Questionnaire, but because the resulting data were of questionable quality, total chemical usage amounts could not be quantified.

I_2 *Copper-clad PWBs.* PWBs or inner layers with non-conductive drilled through-holes that come into the MHC line could add a small amount of copper to the MHC process. Trace amounts of other additives such as arsenic, chromium, and phosphate may also be introduced. This applies to all process alternatives where copper is etched off the boards in the microetch step at the beginning of the MHC process. The amount of copper added from this process is expected to be small, relative to the other chemical inputs. This would be, however, the only expected source of copper for the MHC processes where copper is not otherwise used. This input is not quantified.

I_3 *Water.* Water, usually deionized, is typically used in the MHC process for rinse water, bath make-up, and equipment cleaning. The water consumption of different MHC technologies varies according to the number of rinse tanks used in the MHC process. However, the number of rinse tanks can also vary from facility to facility within a technology category due to differences in facility operating procedures and water conservation measures.

Figure 3.1 Schematic of Overall Material Balance for MHC Technologies

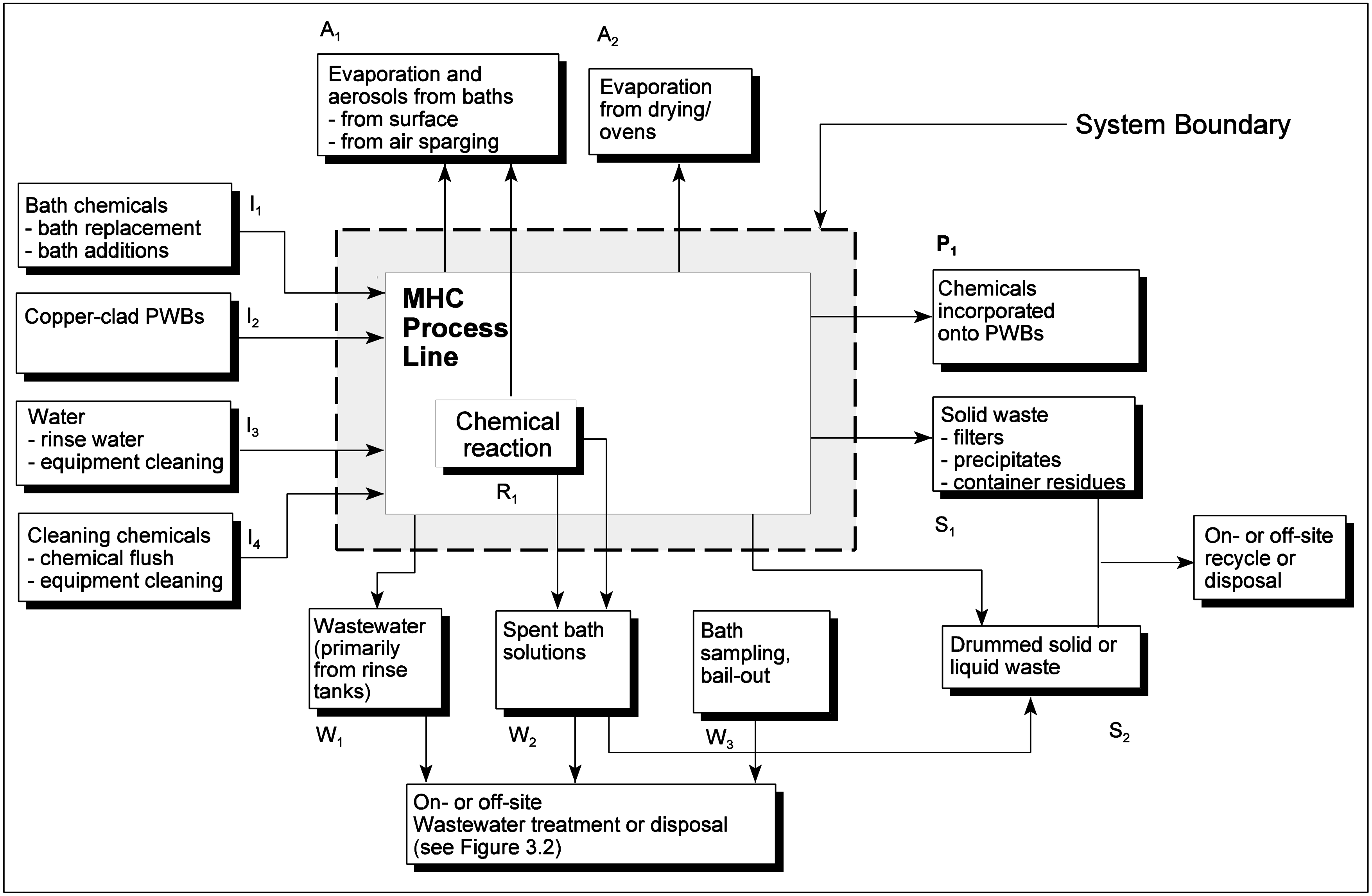
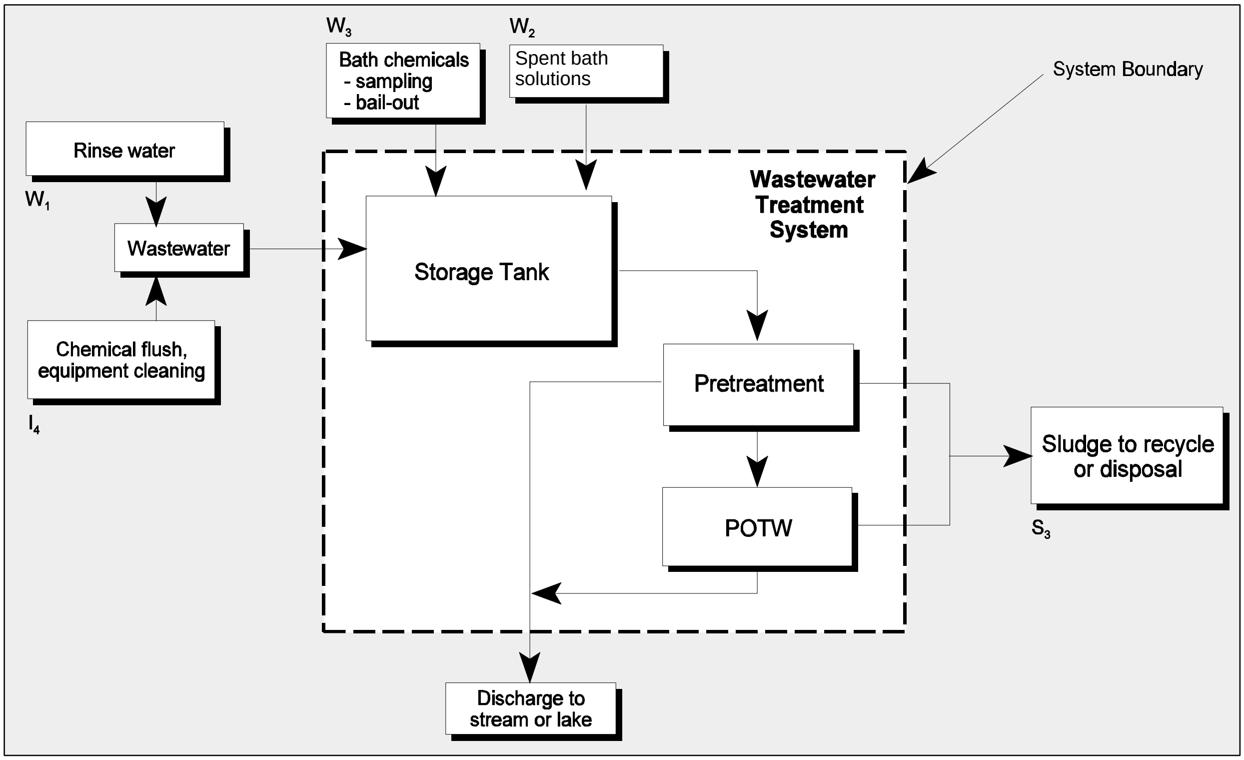


Figure 3.2 Wastewater Treatment Process Flow Diagram



Water usage data collected in the IPC Workplace Practices Questionnaire includes the annual amount of water used for bath make-up and rinse water. Annual water usage in gallons was normalized by dividing the annual water usage in gallons by annual production in ssf of PWB produced. Both annual and normalized water consumption data are summarized in Table 3.1.

Based on the normalized data, on average the questionnaire respondents with non-conveyorized MHC processes use more than ten times as much water as those with conveyorized processes. Due to the variability in questionnaire data, the relative rate of water consumption of the MHC technologies was estimated using both the questionnaire data and a simulation model of the MHC technologies. This is discussed further in Section 5.1, Resource Conservation.

I_4 *Cleaning chemicals.* This includes chemicals used for conveyor equipment cleaning, chemical flush, and other cleaning pertaining to the MHC process line. The amount of cleaning chemicals used is characterized qualitatively based on IPC Workplace Practices Questionnaire data and could include chemicals used to clean conveyor equipment (questionnaire question 3.5) and chemicals used in chemical flush (questionnaire question 4.4). Cleaning chemicals are discussed for specific MHC Technologies in Section 3.1.3.

The total inputs (I_{tot}) = $I_1 + I_2 + I_3 + I_4$.

Table 3.1 Water Usage of MHC Technologies

Process Type	No. of Responses	Water Usage (I_3) (1,000 gal/year)[a]	Water Usage (I_3) (gal/ssf)[a]
Electroless Copper			
Non-conveyorized	35	180 - 16,000 (4,000)	1.2 - 120 (18)
Conveyorized	1	3,300	1
Carbon			
Conveyorized	2	330 (330)	0.28 - 0.29 (0.28)
Conductive Polymer			
Conveyorized	0	no data	no data
Graphite			
Conveyorized	4	561 - 1,200 (914)	1.2 - 3.4 (2.2)
Non-Formaldehyde Electroless Copper			
Non-conveyorized	1	19.5	0.36
Organic-Palladium			
Non-conveyorized	1	7,700	300
Conveyorized	1	881	1.8
Tin-Palladium			
Non-conveyorized	11	300 - 2,900 (1,600)	0.54 - 19 (7.1)
Conveyorized	2	870 - 951 (912)	0.49 - 0.68 (0.58)
All Processes			
Non-conveyorized	48	20 - 16,000 (3,400)	0.36 - 300 (21)
Conveyorized	10	330 - 3,300 (1,000)	0.28 - 3.4 (1.3)

[a] Range and average values from IPC Workplace Practices Questionnaire data.

Outputs

Possible outputs from an MHC process line include PWB products with conductive hole barrels, air emissions, wastewater discharges, and solid wastes.

Product Outputs. Product outputs include:

P_1 *Chemicals incorporated onto PWBs during the MHC process*. This includes copper or other conductive materials deposited into the hole barrels. This output is not quantified.

Air Releases. Chemical emission rates and air concentrations are estimated by air modeling performed in the Exposure Assessment (Section 3.2). The sources of air releases and factors affecting emission rates releases are summarized below.

A_1 *Evaporation and aerosol generation from baths.* Potential air releases include volatilization from open surfaces of the baths as well as volatilization and aerosols generated from air sparging. These releases are quantified in the Exposure Assessment (Section 3.2). Gasses formed in chemical reactions, side reactions, and electroplating in baths could also contribute to air releases, but these are expected to be small compared to volatilization and aerosol losses and are not quantified.

Air releases may be affected by bath temperature, bath mixing methods, and vapor control methods employed. Questionnaire data for bath agitation and vapor control methods are summarized below:[1]

- Most facilities using conveyorized processes use fluid circulation to mix the baths. The only vapor control method reported is enclosure and venting, which is employed for all baths on the conveyorized lines. The process baths are completely enclosed and vented to the outside.
- For facilities using non-conveyorized processes, most use panel agitation and many use fluid circulation. Air sparging is used primarily in electroless copper and microetch baths. (More than one method can be used simultaneously.) Vapor control methods include push-pull for about ½ of the baths, a bath cover for about 1/4 of the baths, with enclosure and other methods reported for a few baths.[2]

Table 3.2 lists average bath surface area, volume, and bath temperature data from the IPC Workplace Practices Questionnaire. Some of this information (both surface area and temperature) is used to model air releases in the Exposure Assessment. Surface areas are calculated from reported bath length and width data. Larger bath surface areas enhance evaporation. Most baths are maintained at elevated temperatures which also enhances chemical evaporation.

A_2 *Evaporation from drying/oven.* Air losses due to evaporation from drying steps applies primarily to carbon and graphite processes with air knife/oven steps. Releases are discussed qualitatively in Section 3.1.3.

The total outputs to air (A_{tot}) = $A_1 + A_2$.

Table 3.2 Average Bath Dimensions and Temperatures for All Processes[a]

Bath	No. of Responses	Length (in.)	Width (in.)	Surface Area (sq. in.)	Volume (gal.)	Temp (ºF)
Electroless Copper, non-conveyorized						
Accelerator	31	41	23	874	123	81
Acid Dip	12	38	24	795	105	76
Anti-Tarnish	20	43	22	907	109	84
Catalyst	35	41	23	890	119	98
Conditioner/Cleaner	35	41	23	882	119	137

[1] From questionnaire question 4.1.

[2] Push-pull ventilation combines a lateral slot hood at one end of the tank with a jet of push air from the opposite end. It is used primarily for large surface area tanks where capture velocities are insufficient to properly exhaust fumes from the tank.

Bath	No. of Responses	Length (in.)	Width (in.)	Surface Area (sq. in.)	Volume (gal.)	Temp (ºF)
Electroless Copper	35	45	34	1,618	229	102
Microetch	35	41	24	937	148	95
Other	9	41	16	682	116	72
Predip	35	40	23	875	117	79
Electroless Copper, conveyorized						
Acid Dip	1	29	24	696	185	96
Catalyst	1	29	24	696	37	116
Conditioner/Cleaner	1	120	24	2,880	80	130
Electroless Copper	1	335	24	8,028	185	91
Microetch	1	38	24	912	54	98
Other	1	59	24	1,416	43	101
Predip	1	19	24	456	34	
Carbon, conveyorized						
Anti-Tarnish	1	23	44	1,012	25	86
Carbon	4	49	44	2,156	128	87
Cleaner	2	44	44	1,936	48	129
Conditioner	2	44	44	1,936	47	81
Microetch	2	54	44	2,354	100	116
Conductive Polymer, conveyorized						
Catalyst	1	48	30	1440	172	198
Conditioner/Cleaner	2	22	30	660	82	158
Microetch	1	19	30	570	82	72
Polymer	1	24	30	720	26	41
Graphite, conveyorized						
Anti-Tarnish	3	20	26	532	29	75
Conditioner/Cleaner	4	30	28	833	43	125
Graphite	4	30	28	833	37	82
Microetch	4	34	28	938	55	88
Non-Formaldehyde Electroless Copper, non-conveyorized						
Accelerator	1	12	32	384	40	124
Catalyst	1	12	32	384	40	100
Conditioner/Cleaner	1	12	32	384	40	124
Electroless Copper	1	32	16	512	62	163
Microetch	1	12	32	384	40	103
Predip	1	12	32	384	40	
Organic-Palladium, non-conveyorized						
Acid Dip	1	20	63	1,260	274	70
Cleaner	1	18	63	1,134	247	122
Conditioner	1	20	63	1,260	274	105
Conductor	1	15	63	945	206	113

Bath	No. of Responses	Length (in.)	Width (in.)	Surface Area (sq. in.)	Volume (gal.)	Temp (ºF)
Microetch	1	15	63	945	206	78
Other	1	12	63	756	157	
Post Dip	1	15	63	945	206	74
Organic-Palladium, conveyorized						
Acid Dip	1	12	49	588	24	79
Cleaner	1	24	49	1,176	37	120
Conditioner	1	60	49	2,940	74	100
Conductor	1	98	49	4,802	108	115
Microetch	1	25	49	1,225	37	75
Other	1	24	49	1,176	48	81
Post Dip	1	26	49	1,274	45	77
Tin-Palladium, non-conveyorized						
Accelerator	10	35	17	580	67	134
Acid Dip	4	29	19	532	59	76
Anti-Tarnish	3	34	10	344	51	73
Catalyst	11	31	16	515	56	111
Conditioner/Cleaner	11	34	18	576	65	164
Microetch	9	30	17	520	64	76
Other	4	31	18	593	61	74
Predip	11	31	16	497	53	75
Tin-Palladium, conveyorized						
Accelerator	2	40	33	1,341	80	103
Acid Dip	2	24	33	780	53	94
Anti-Tarnish	1	30	30	900	80	71
Catalyst	2	86	33	2,742	173	117
Conditioner/Cleaner	2	45	33	1,410	98	114
Microetch	2	25	33	810	58	92
Other	1	30	30	900	80	75
Predip	2	24	33	780	58	81

[a] Based on IPC Workplace Practices Questionnaire data.

Water Releases. Potential outputs to water include chemical-contaminated wastewater from rinse tanks, spent bath solutions, and liquid discharges from bath sampling and bail-out. Chemical-contaminated rinse water is the largest source of wastewater from most MHC process lines and primarily results from drag-out or drag-in. Drag-out or drag-in is the transfer of chemicals from one bath to the next by dragging bath solution on a PWB out of one bath and into the subsequent bath. Drag-in or drag-out losses are estimated to be approximately 95 percent of uncontrolled bath losses (i.e., losses other than from bath replacement, bail-out, and sampling) (Bayes, 1996). The quantity of chemicals lost can be reduced through operational practices such as increased drip time (see Section 6.1, Pollution Prevention). Potential water releases are discussed further below.

W_1 *Wastewater*. MHC line wastewater primarily consists of chemical-contaminated water from rinse tanks used to rinse residual chemistry off PWBs between process steps. Water usage and wastewater composition were addressed by several questions in the IPC Workplace Practices Questionnaire, with resulting data of variable to poor quality. Because the volume of rinse water used in MHC processes is much greater than water used in all other applications, the quantity of wastewater generated is assumed to be equal to water usage (I_3). The previous discussion of water usage data also applies to wastewater amounts.

W_2 *Spent bath solution.* Bath concentrations vary over time (as the bath ages) and as PWBs are processed through the baths. Spent bath solutions are chemical bath solutions that have become too contaminated or depleted to properly perform a desired function. Spent bath solutions are removed from a process bath when a chemical bath is replaced.

As noted above, bath formulations and chemical constituents of those formulations were characterized based on publicly-available bath chemistry data and some proprietary bath chemistry data (see Section 2.1.4 and Appendix B). For the purposes of this assessment, chemical concentrations within the spent baths were assumed to be the same as bath make-up concentrations. The amount of spent bath disposed was addressed in the IPC Workplace Practices Questionnaire question 4.3, Chemical Bath Replacement, but many respondents did not have this information. Therefore, total chemical disposal amounts have not been quantified. Table 3.3 presents a summary of spent bath treatment methods reported in the questionnaire by MHC technology.

W_3 *Bath sampling and bail-out.* This includes bath solutions disposed of after sampling and analysis and bath bail-out (sometimes done prior to bath additions). In some cases sampling may be performed at the same time as bail-out if the process bath is on a controller.

Routine bail-out activities could result in a large amount of bath disposal. Because this activity was not included in the IPC Workplace Practices Questionnaire there is only limited information on frequency or amount of bail-out expected. Chemical loss due to bath sampling was assumed to be negligible.

The total outputs to water (Wtot) = $W_1 + W_2 + W_3$.

Wastewater Treatment. Figure 3.2 showed the overall water and wastewater treatment flows, including chemical bath solutions and wastewater inputs to treatment, any pre-treatment or treatment performed on-site or off-site, sludge generated from either on-site or off-site treatment, and final effluent discharge to surface water. PWB manufacturers typically combine wastewater effluent from other PWB manufacturing processes prior to on-site wastewater pretreatment. The pretreated wastewater is then discharged to a POTW.

Table 3.3 Spent Bath Treatment and Disposal Methods

Process Alternative	Total No. of Baths	Precipitation Pretreatment[a]	pH Neutralization[a]	Disposed to Sewer[a]	Drummed[a]	Recycled On-Site[a]	Other On-Site Treatment[a]	Sent to Recycle[a]	Discharged to POTW[a]	Other Off-Site Treatment[a]
Electroless Copper, non-conveyorized	240	123	87	3	16	11	11	22	29	27
Electroless Copper, conveyorized	7	7	0	0	0	7	0	0	0	0
Carbon, conveyorized	10	7	3	0	0	0	0	0	0	0
Conductive Polymer, conveyorized	3	0	3	0	0	0	0	0	0	0
Graphite, conveyorized	13	4	8	0	2	0	1	0	4	0
Non-Formaldehyde Electroless Copper, non-conveyorized	5	0	0	0	0	0	0	0	0	0
Organic-Palladium, non-conveyorized	7	0	7	0	0	0	0	0	0	0
Organic-Palladium, conveyorized	7	4	0	0	0	0	0	0	0	0
Tin-Palladium, non-conveyorized	64	52	56	0	6	0	1	0	6	11
Tin-Palladium, conveyorized	14	4	3	0	0	0	0	0	0	0

[a] Number of affirmative responses for any bath from the IPC Workplace Practices Questionnaire, for all facilities using a technology category.

Table 3.4 summarizes treatment and discharge methods and copper concentrations in PWB plant discharges reported in *Pollution Prevention and Control: Analysis of Survey Results* (EPA, 1995a). The primary purpose of most PWB manufacturer's wastewater treatment systems is the removal of dissolved metals. This is accomplished with conventional metals precipitation systems (a series of unit operations using hydroxide precipitation followed by separation of the precipitated metals), ion exchange-based metals removal systems, and combined precipitation/ion exchange systems. The most common type is conventional metals precipitation, which includes precipitation units followed by either clarifiers or membrane filters for solids separation. The use of clarifiers is the predominant method for separation of precipitated solids from the wastewater. Wastewater treatment systems are discussed further in Section 6.2, Recycle, Recovery, and Control Technologies Assessment.

Table 3.4 Treatment and Discharge Methods and Copper Concentration Summarized from Pollution Prevention and Control Survey

Respondent Identification No. By MHC Technology	Copper Discharge Limitations		Wastewater Copper Concentration (mg/l)	Discharge	Type of Wastewater Treatment
	Max (mg/l)	Avg (mg/l)			
Electroless Copper					
31838	3	1.5	NR	indirect	
36930	4.34	2.6	NR	indirect	
44486	4.5	2.7	NR	indirect	precipitation
955703	3	2.07	0.4	indirect	electrowinning/ion exchange
36930	2.59	1.59	1	indirect	ion exchange
237900	2.7	1	1.2	indirect	precipitation/clarifier
502100	1	1.5	2	indirect	
358000	2	1.5	2	indirect	ion exchange
959951	3.22	0.45	5	indirect	
t3	2.7	2.7	5	indirect	precipitation/membrane
44657	3	2.07	7	indirect	precipitation/clarifier
55595	NR	NR	10	direct	precipitation/filter press
3023	1.5	none	12.5	indirect	ion exchange, precipitation/ membrane, resist strip
42692	4.5	2.7	17.5	direct	ion exchange
6710	4.5	0.37	20	indirect	precipitation/clarifier
41739	4	0.4	25	direct	precipitation/membrane
955099	1.5	none	30	indirect	precipitation/clarifier
t2	2.2	2.07	30	indirect	precipitation/clarifier, sludge dryer, air scrubber
947745	3.38	2.07	30	indirect	precipitation/clarifier
42751	3	2.07	33	indirect	precipitation/clarifier, polishing filter, filter press

Respondent Identification No. By MHC Technology	Copper Discharge Limitations		Wastewater Copper Concentration (mg/l)	Discharge	Type of Wastewater Treatment
	Max (mg/l)	Avg (mg/l)			
t1	1	0.03	35	direct	precipitation/clarifier, sludge dryer, chemical tester
946587	3.4	none	40	indirect	precipitation/clarifier
25503	3	2.07	40	indirect	ion exchange
965874	3.38	2.07	40	indirect	ion exchange/electrowinning
273701	3.38	2.07	50	indirect	ion exchange, electrowinning
953880	0.25	none	57	indirect	
133000	1.5	none	60	indirect	precipitation/clarifier, sludge dryer
32482	3.38	2.07	65	indirect	precipitation/clarifier
107300	2	1	80	direct	precipitation/clarifier, sludge dryer, equalization
33089	3.38	2.07	300	indirect	precip/clarifier, filter press
3470	1.5	2.07		indirect	ion exchange
Graphite					
43841	4.3	2.6	200	indirect	precipitation/filtration, filter press, equalization, etc.
Palladium					
279	3	2.02	NR	direct	
37817[a]	4.5	3.5	3	indirect	ion exchange, electrowinning
29710	0.49	0.41	4	direct	ion exchange
43694	3	2.07	30	indirect	ion exchange
Average	2.75	1.50	35.70		
Median	3	2.07	30		
Max	4.50	3.50	300.00		
Min	0.25	0.03	0.2		
Standard Deviation	1.20	0.97	57.54		

[a] Respondent 37817 reported Cu max = 5.0 mg/l; assumed 4.5 mg/l in compliance with Federal regulations.
NR: Not Reported.
Source: EPA, 1995a.

Following any in-house wastewater treatment, facilities release wastewater either directly to surface water or indirectly to a POTW. Sludge from on-site wastewater treatment is discussed in the section below (Solid Waste). The data for discharge type (direct or indirect) are discussed for specific processes in Section 3.1.3.

Permit data for releases were not collected; this was deleted from the questionnaire upon request by industry participants. However, PWB manufacturers who responded to the IPC

Workplace Practices Questionnaire were asked to provide the maximum and average metals concentrations (e.g., copper, palladium, tin) in wastewater from their MHC line (questionnaire question 2.3, Wastewater Characterization). Several respondents indicated the question could not be answered, did not respond to this question, or listed their POTW permit discharge limits. This is because there are many sources of metals, especially copper, in PWB manufacturing. PWB manufacturers typically combine effluents from different process steps prior to wastewater treatment. Thus, the chemical constituents and concentration in wastewater could not be characterized.

Solid Waste. Solid wastes are generated by day-to-day MHC line operation and by wastewater treatment of MHC line effluents. Some of these solid wastes are recycled, while others are sent to incineration or land disposal. Solid waste outputs include:

S_1 *Solid waste.* Solid wastes could include spent bath filters, chemical precipitates (e.g., $CuSO_4$ crystals from etch bath), packaging or chemical container residues, and other solid waste from the process line, such as off-specification PWBs. Chemical baths are typically replaced before precipitation occurs. However, if precipitation does occur, some precipitates, such as copper sulfate crystals, may be recycled. Container residue is estimated by EPA to be up to four percent of the chemicals use volume (Froiman, 1996). An industry reviewer indicated this estimate would only occur with very poor housekeeping practices and is not representative of the PWB industry (Di Margo, 1996). The questionnaire data did not include chemical characterization of solid wastes.

S_2 *Drummed solid or liquid waste*. This includes other liquid or solid wastes that are drummed for on-site or off-site recycling or disposal. Some spent baths and wastes can be recycled or recharged, such as etchant. No data were available to characterize these wastes.

S_3 *Sludge from on-site wastewater treatment.* Questionnaire respondents were asked to report the amount of sludge they generated during on-site wastewater treatment that could be attributed to MHC line effluents (questionnaire question 2.4, Wastewater Discharge and Sludge Data). Both annual quantities and data normalized to pounds of sludge per ssf of PWB produced are presented in Table 3.5. However, many PWB manufacturers have indicated that the amount of sludge from the MHC process cannot be reliably estimated since effluents from various PWB manufacturing process steps are combined prior to wastewater treatment. In addition, the amount of sludge generated during wastewater treatment varies according to the MHC technology used, the treatment method used, facility operating procedures, the efficiency with which bath chemicals and rinse water are used, and other factors. Thus, the comparative amount of sludge generated due to the choice of an MHC technology could not be determined, nor were data available to characterize the concentrations of metals contributed by the MHC line.

The total solid waste output (S_{tot}) = $S_1 + S_2 + S_3$.

Table 3.5 Sludge Generation from Wastewater Treatment of MHC Line Effluents

Process Type	No. of Responses	Sludge (S_4) (lbs/year)[a]	Sludge (S_4) (lbs/1,000 ssf)[a]
Electroless Copper			
Non-conveyorized	35	600 - 100,000 (25,000)	2 - 530 (96)
Conveyorized	1	1,000	0.31
Carbon			
Conveyorized	2	no data	no data
Conductive Polymer			
Conveyorized	0	no data	no data
Graphite			
Conveyorized	4	5.5 - 920 (380)	0.01 - 5.6 (2.2)
Non-Formaldehyde Electroless Copper			
Non-conveyorized	1	200	3.7
Organic-Palladium			
Non-conveyorized	1	5,000	190
Conveyorized	1	21,600	45
Tin-Palladium			
Non-conveyorized	11	200 - 24,000 (6,700)	1.3 - 94 (27)
Conveyorized	2	17,000	9.5
All Processes			
Non-conveyorized	48	200 - 100,000 19,500)	1.3 - 530 (79)
Conveyorized	10	5.5 - 21,600 (6,800)	0.01 - 45 (10)

[a] Range and average values for each from questionnaire data.

Transformations. Transformations within the MHC system boundary could include:

R_1 *Chemical reaction gains or losses*. This includes any chemical species consumed, transformed, or produced in chemical reactions and side reactions occurring in the process baths. Reactions and side reactions within the baths could result in either chemical losses or production of new chemicals as degradation products. One important set of reactions involve formaldehyde in the electroless copper process. Formaldehyde, which is utilized as a reducing agent, is converted to formic acid. In a secondary or side reaction formaldehyde also breaks down into methanol and the formate ion. This reaction is the only source of formate ion in the electroless copper bath. Other side reaction products include BCME (bis-chloromethyl ether) which is produced in a reaction between hydrochloric acid and formaldehyde (Di Margo, 1996).

The overall material balance: $I_{tot} = A_{tot} + W_{tot} + S_{tot} + P_1 \pm R_1$.

3.1.3 Source and Release Information For Specific MHC Technology Categories

This section describes the specific inputs and outputs in the material balance for each MHC technology. To facilitate comparison among process alternatives, and to adjust for the wide variations in the data due to differing sizes of PWB facilities, data are presented both as reported in the IPC Workplace Practices Questionnaire, and normalized by production amounts (annual ssf of PWB produced). Average values from the IPC Workplace Practices Questionnaire database are reported here for summary purposes.

Electroless Copper Process

Figure 3.3 illustrates the generic electroless copper process steps and typical bath sequence evaluated in the CTSA. The process baths depicted in Figure 3.3 represent an integration of the various products offered within the electroless copper technology category. The number and location of rinse steps shown in the figure are based on the IPC Workplace Practices Questionnaire data. Figure 3.3 lists the types and sequence of baths in a generic electroless copper line, but the types and sequence of baths in an actual line could vary.

Water Usage (I_3) and Wastewater (W_1). Water usage data from the IPC Workplace Practices Questionnaire were presented in Table 3.1; the amount of wastewater generated is assumed equal to the amount of water used. Of respondents using an electroless copper process, 11 discharge wastewater directly to a stream or river following the appropriate treatment while 20 facilities use indirect discharge (e.g., to a POTW). (Five facilities did not respond to the question.) While several facilities using electroless copper completed the questionnaire, only a single facility used the conveyorized process. This large facility produces over three million ssf of PWB per year. In summary:

- Reported water usage for the facility using a conveyorized electroless copper process is 3.3 million gallons per year, or about one gallon per ssf of PWB produced.
- Reported water usage for the facilities using non-conveyorized processes average 4.0 million gallons per year, or 18 gallons per ssf of PWB produced.

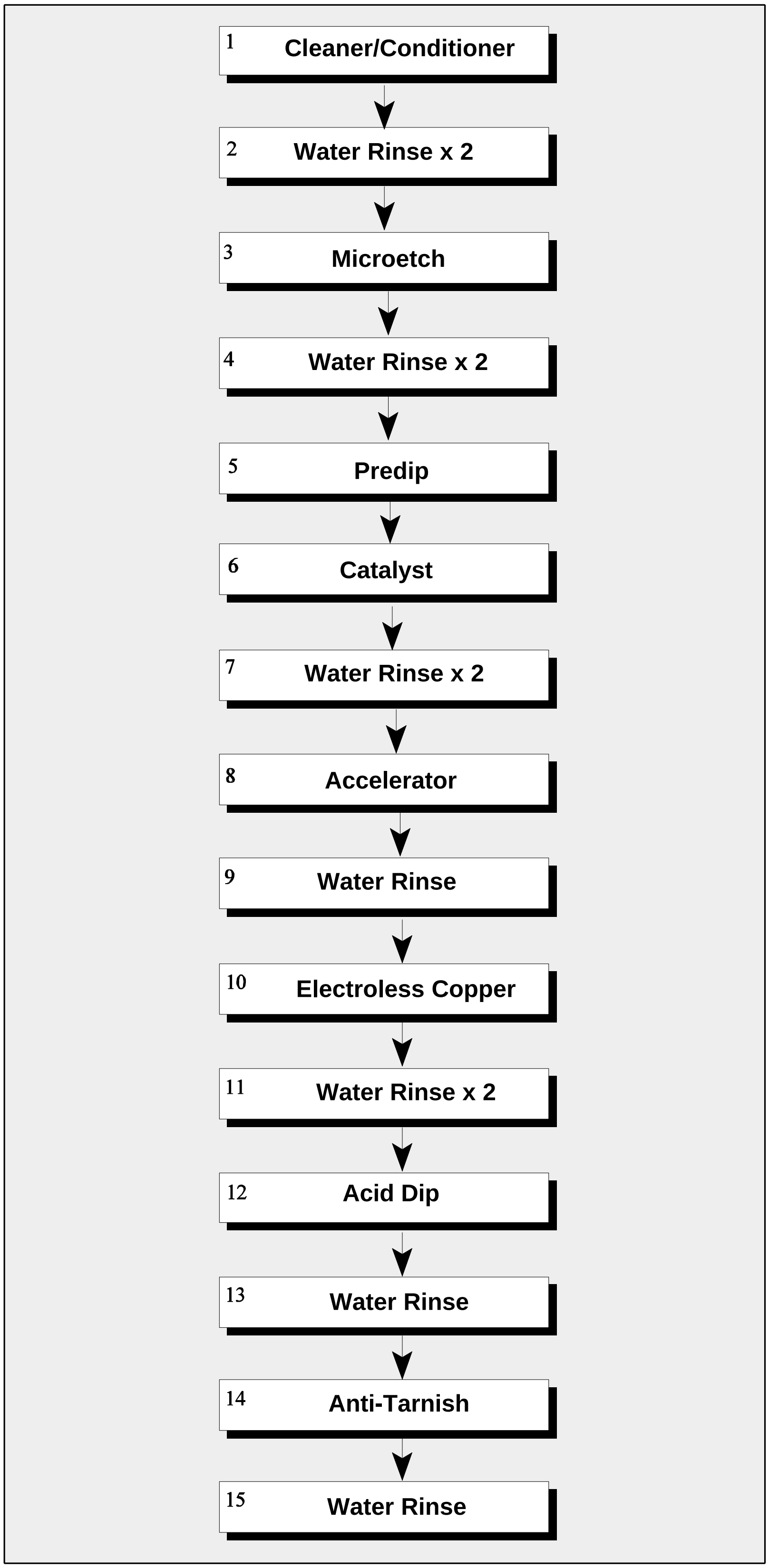
Chemical constituents and concentrations in wastewater could not be adequately characterized.

Cleaning Chemicals (I_4). Chemicals used for cleaning of electroless copper equipment, as reported in the IPC Workplace Practices Questionnaire, include water, sodium persulfate, sulfuric acid, hydrogen peroxide, nitric acid, and "211 solvent."

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the electroless copper process. The amount of bath chemicals used could not be quantified from questionnaire data.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined from the data. Spent bath treatment methods were presented in Table 3.3. Precipitation pretreatment and on-site recycling are reported treatment methods for the conveyorized electroless copper process; precipitation pretreatment and pH neutralization were most commonly reported as methods for the non-conveyorized electroless copper process.

Figure 3.3 Generic Electroless Copper Process Steps and Typical Bath Sequence



Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). To summarize questionnaire data:

- For the single conveyorized electroless copper process, fluid circulation is used in all but the microetch bath. Enclosure is used for vapor control for all baths.
- For non-conveyorized electroless copper facilities, panel agitation is used in most baths, fluid circulation in about 1/3 of the baths, air sparging is primarily used in electroless copper and a few microetch baths, and a few baths use other mixing methods. Vapor control methods include push-pull for about ½ of the baths, a bath cover for about 1/4 of the baths, with enclosure and other methods reported for a few of the baths.
- Table 3.2 lists bath surface area, volume, and bath temperature data from the IPC Workplace Practices Questionnaire.

Evaporation From Drying/Oven (A_2). This source of air emissions does not apply to electroless copper processes since oven drying is not required and air drying immediately follows water rinsing.

Chemicals Incorporated Onto PWBs (P_1). Copper is added to the boards in the electroless copper process. Small quantities of palladium from the catalyst are also deposited on the PWBs.

Drummed Solid or Liquid Waste (S_2). This was reported as a spent bath treatment method for either solution or sludge for 16 out of 240 baths by the non-conveyorized electroless copper facilities (see Table 3.3). The total quantity of drummed waste was not reported.

Sludge Amounts From On-Site Treatment (S_3). Sludge generation data are presented in Table 3.5. In general:

- Reported sludge amounts for the facility using a conveyorized process are 1,000 lbs/year, or 0.31 lbs per 1,000 ssf of PWB produced.
- Reported sludge amounts for the facilities using non-conveyorized processes average 25,000 lbs/year, or 96 lbs per 1,000 ssf of PWB produced.

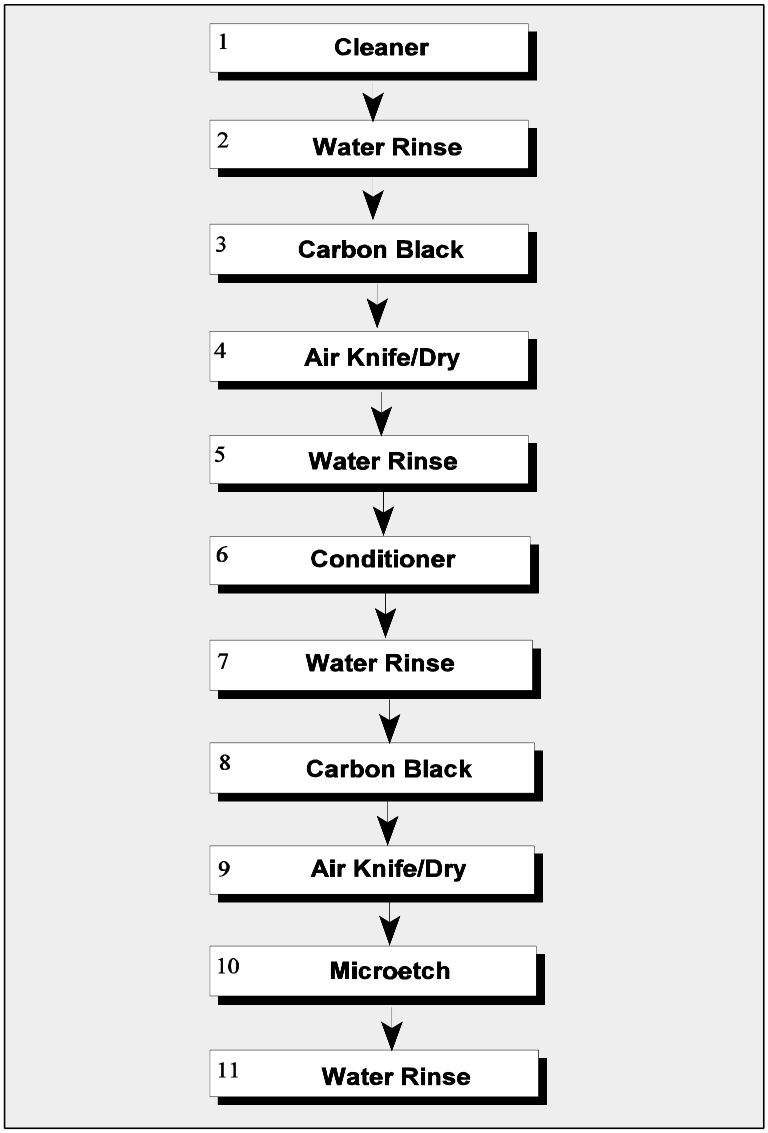
Metal concentrations in sludge could not be adequately characterized.

Chemical Reaction Gains or Losses (R_1). The most well-documented chemical reactions in electroless copper baths involve formaldehyde. Formaldehyde is used as a copper reducing agent, and in this reaction formaldehyde is converted to formic acid and hydrogen gas. In a secondary (unwanted) reaction called the Cannizzaro reaction, formaldehyde breaks down to methanol and the formate ion which in a caustic solution forms sodium formate. A study by Merix Corporation found that for every one mole of formaldehyde reacting in the intended copper deposition process, approximately one mole was reacting with hydroxide in the Cannizzaro reaction. Other studies have found that the side reaction tendency goes up with the alkalinity of the process bath (Williamson, 1996). A search of literature references failed to produce sufficient quantifiable data to characterize these reactions.

Carbon Process

Figure 3.4 illustrates the carbon process steps and bath sequence evaluated in the CTSA. The number and location of rinse steps shown in the figure are based on IPC Workplace Practices Questionnaire data. Thus, Figure 3.4 lists the types and sequence of baths in a generic carbon line, but the types and sequence of baths in an actual line could vary. Both carbon facilities in the IPC Workplace Practices Questionnaire database use conveyorized equipment.

Figure 3.4 Generic Carbon Process Steps and Typical Bath Sequence



Water Usage (I_3) and Wastewater (W_1). Water usage data were summarized in Table 3.1; wastewater generation is assumed equal to water usage. Reported water usage for the two facilities is 330,000 gallons per year, or 0.28 gallon per ssf of PWB produced. Both carbon facilities use indirect discharge of wastewater. Chemical constituents and concentrations in wastewater could not be adequately characterized.

Cleaning Chemicals (I_4). Only water is used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the carbon process. The amount of bath chemicals used could not be quantified from the data.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined from available data. Spent bath treatment methods were presented in Table 3.3. Precipitation pretreatment and pH neutralization are reported methods for carbon processes.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). For both facilities using conveyorized carbon, fluid circulation is used for bath agitation and enclosure is used for vapor control for all baths. Table 3.2 lists bath surface area, volume, and bath temperature data.

Evaporation From Drying/Oven (A_2). Air knife/oven drying occurs after the carbon black and fixer steps. Any solution adhering to the boards would be either blown off the boards and returned to the sump, or volatilized in the oven. Air emissions from air knife/oven drying were not modeled.

Chemicals Incorporated Onto PWBs (P_1). Carbon black is added to the boards in this process.

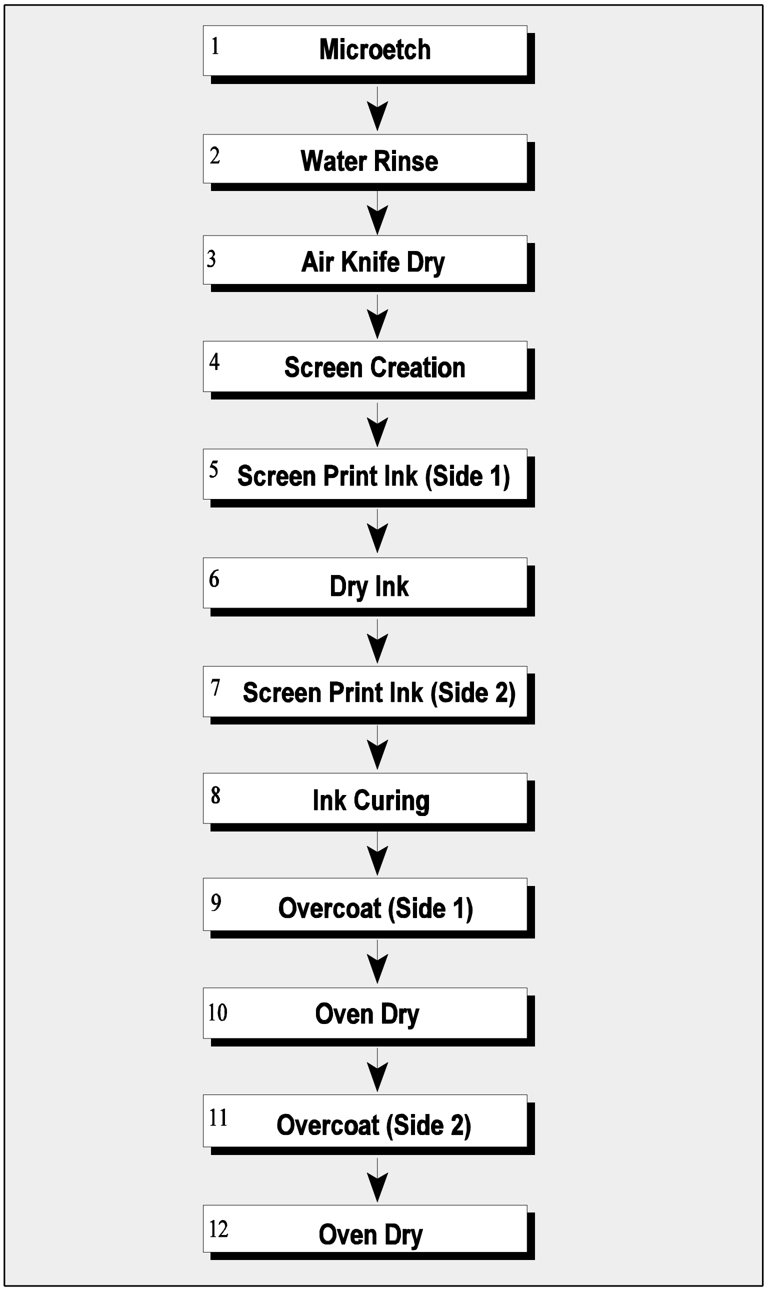
Drummed Solid or Liquid Waste (S_2). This was not reported as a spent bath treatment method for carbon processes (see Table 3.3).

Sludge Amounts From On-Site Treatment (S_3). Sludge data were not reported for the carbon processes.

<u>Conductive Ink Process</u>

A generic conductive ink sequence is shown in Figure 3.5. Source release data for conductive ink are not available since there are no facilities currently using the process for the production of multi-layer PWBs.

Figure 3.5 Generic Conductive Ink Process Steps

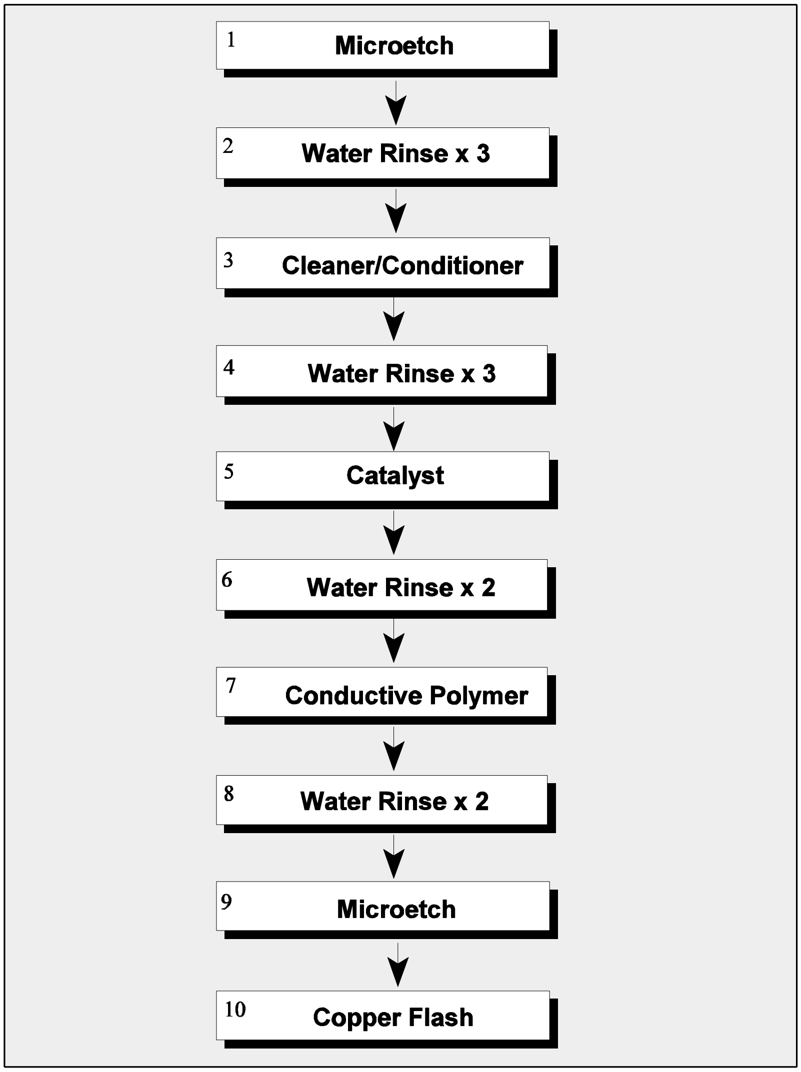


Conductive Polymer Process

Figure 3.6 illustrates the generic conductive polymer process steps and typical bath sequence evaluated in the CTSA. The number and location of rinse steps shown in the figure are based on IPC Workplace Practices Questionnaire data. Thus, Figure 3.6 lists the types and sequence of baths in a generic conductive polymer line, but the types and sequence of baths in an actual line could vary. The single conductive polymer facility in the IPC Workplace Practices Questionnaire data uses conveyorized equipment.

Water Usage (I_3) and Wastewater (W_1). The single facility using a conductive polymer process uses indirect discharge of wastewater.

Figure 3.6 Generic Conductive Polymer Process Steps and Typical Bath Sequence



Cleaning Chemicals (I_4). Only water is used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire data.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the conductive polymer process. The amount of bath chemicals used could not be quantified from the data.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined from the data. Spent bath treatment methods are presented in Table 3.3. pH neutralization is reported as a treatment method for the conductive polymer process.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). The facility using a conveyorized conductive polymer process reported using fluid circulation for all baths and enclosure for vapor control for all baths. Table 3.2 shows bath surface area, volume, and bath temperature data.

Evaporation From Drying/Oven (A_2). This source of air emissions does not apply to the conductive polymer process since oven drying is not required and air drying immediately follows water rinsing.

Chemicals Incorporated Onto PWBs (P_1). A polymer is added to the boards in this process.

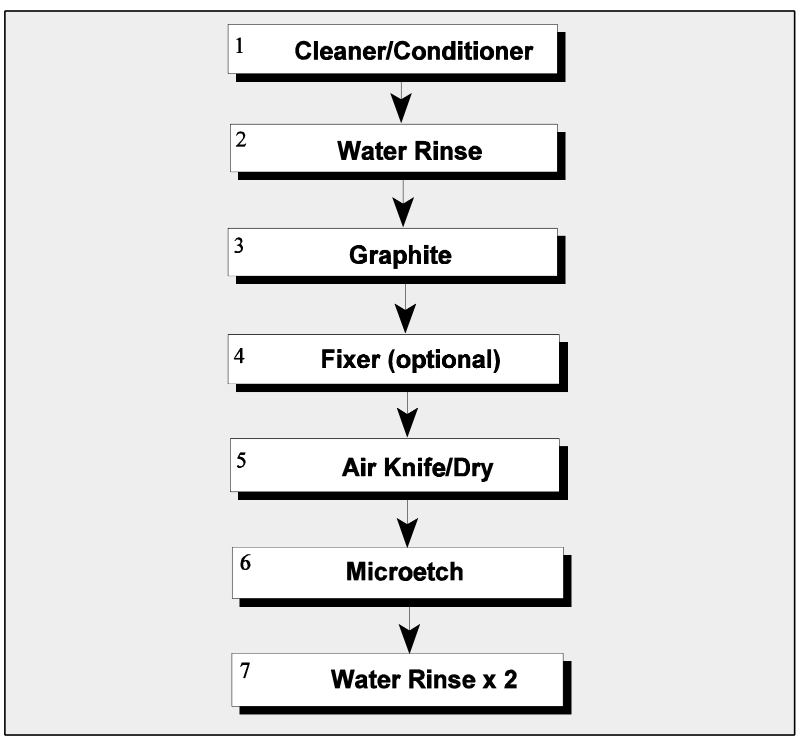
Drummed Solid or Liquid Waste (S_2). This was not reported as a spent bath treatment method for the conductive polymer process (see Table 3.3).

Sludge Amounts From On-Site Treatment (S_3). Sludge amounts were not reported for this process.

Graphite Process

Figure 3.7 illustrates the generic graphite process steps and typical bath sequence evaluated in the CTSA. The process baths depicted in Figure 3.7 represent an integration of the various products offered within the graphite technology category. The number and location of rinse steps shown in the figure are based on the IPC Workplace Practices Questionnaire data. Thus, Figure 3.7 lists the types and sequence of baths in a generic graphite line, but the types and sequence of baths in an actual line could vary. The four facilities in the IPC Workplace Practices Questionnaire database use conveyorized equipment.

Figure 3.7 Generic Graphite Process Steps and Typical Bath Sequence



Water Usage (I_3) and Wastewater (W_1). Water usage data are presented in Table 3.1. For graphite, two facilities use direct and two facilities use indirect discharge. Reported water usage for the facilities using a conveyorized process averages 914,000 gallons per year, or 2.2 gallons per ssf of PWB produced.

Cleaning Chemicals (I_4). Chemicals used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire, include water and ammonia.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the graphite process. The amount of chemicals used could not be determined from the data.

Spent Bath Solutions (W_2). Spent bath treatment methods are presented in Table 3.3. Precipitation pretreatment, pH neutralization, and discharge to a POTW are reported methods for the graphite process.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). To summarize Workplace Practices data:

- For facilities using a conveyorized graphite process, fluid circulation is used in most baths. Enclosure for vapor control is employed for all of the baths.
- Table 3.2 lists bath surface area, volume, and bath temperature data from the IPC Workplace Practices Questionnaire.

Evaporation From Drying/Oven (A_2). Air knife/oven drying occurs after the graphite and fixer steps. Any solution adhering to the boards would be either blown off the boards and returned to the sump, or volatilized in the oven. Air emissions from air knife/oven drying were not modeled.

Chemicals Incorporated Onto PWBs (P_1). Graphite is added to the boards in this process.

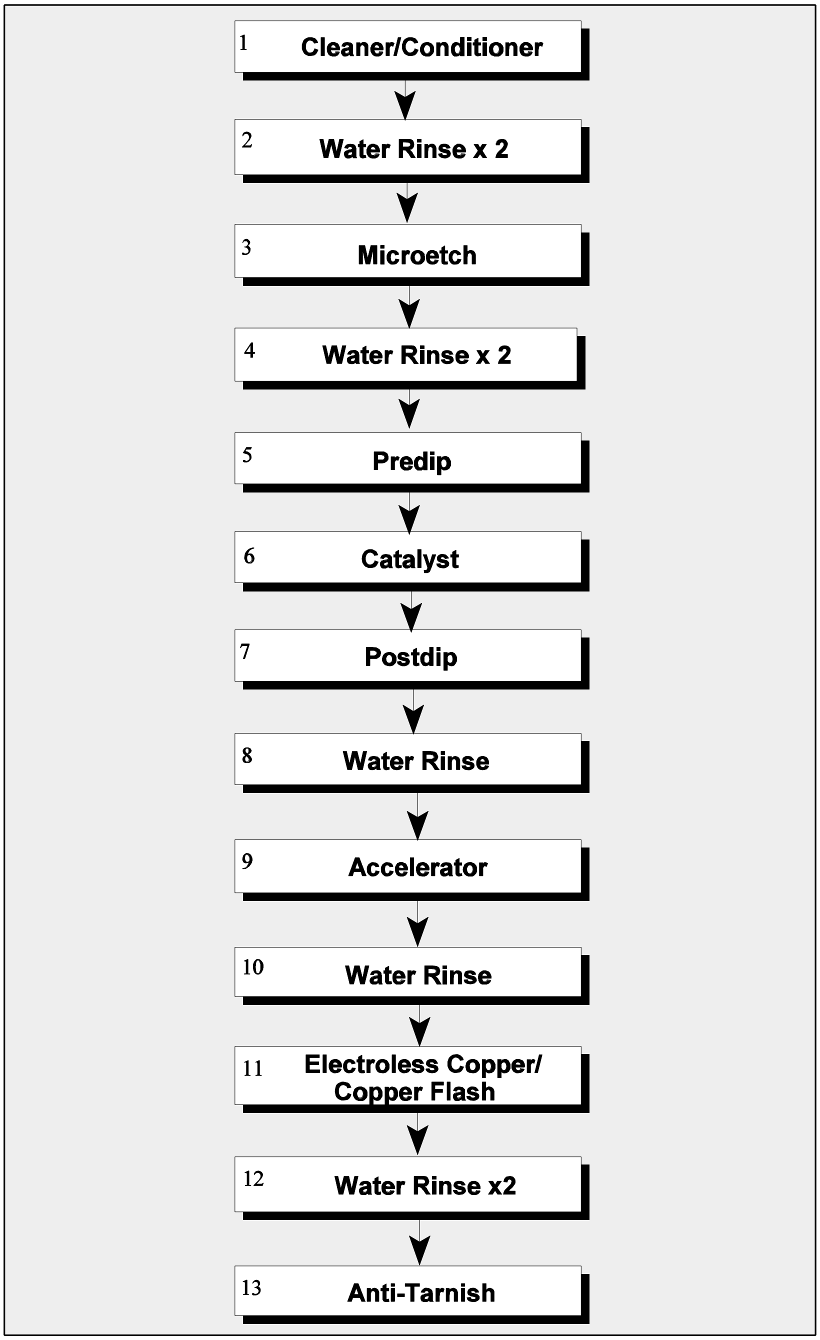
Drummed Solid or Liquid Waste (S_2). This was reported as a spent bath treatment method for two out of 13 baths by the facilities using a conveyorized graphite process (see Table 3.3).

Sludge Amounts From On-Site Treatment (S_3). Sludge generation data are presented in Table 3.5. Reported sludge amounts for the facilities using a conveyorized process average 380 lbs/year, or 2.2 lbs per 1,000 ssf of PWB produced.

<u>Non-Formaldehyde Electroless Copper Process</u>

Figure 3.8 illustrates the generic non-formaldehyde electroless copper process steps and typical bath sequence evaluated in the CTSA. The number and location of rinse steps shown in the figure are based on IPC Workplace Practices Questionnaire data. Thus, Figure 3.8 lists the types and sequence of baths in a generic non-formaldehyde electroless copper line, but the types and sequence of baths in an actual line could vary. The single non-formaldehyde electroless copper facility in the IPC Workplace Practices Questionnaire database uses a non-conveyorized equipment configuration. This is a small facility that produces just over 50,000 ssf of PWB per year.

Figure 3.8 Generic Non-Formaldehyde Electroless Copper Process Steps and Typical Bath Sequence



Water Usage (I_3) and Wastewater (W_1). Water usage data for the single non-formaldehyde electroless copper facility in the IPC Workplace Practices Questionnaire database were presented in Table 3.1; wastewater generation is assumed equal to water usage. The non-formaldehyde electroless copper facility indicated it discharges wastewater directly to a receiving stream, rather than a POTW. Chemical constituents and concentrations in wastewater could not be adequately characterized.

Cleaning Chemicals (I_4). Only water is used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the non-formaldehyde electroless copper process. The amount of bath chemicals used could not be quantified from data.

Spent Bath Solutions (W_2). The quantity of spent bath solutions could not be determined from available data. Spent bath treatment methods are presented in Table 3.3. No treatment methods were reported for the non-formaldehyde electroless copper process.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). The non-formaldehyde electroless copper facility uses panel agitation in all baths and fluid circulation in most baths. The only vapor control method reported is the use of a removable bath cover for the microetch bath. Table 3.2 lists bath surface area, volume, and bath temperature data from the IPC Workplace Practices Questionnaire.

Evaporation From Drying/Oven (A_2). This source of air emissions does not apply to non-formaldehyde electroless copper processes since oven drying is not required and air drying immediately follows water rinsing.

Chemicals Incorporated Onto PWBs (P_1). Copper is added to the boards in the non-formaldehyde electroless copper process.

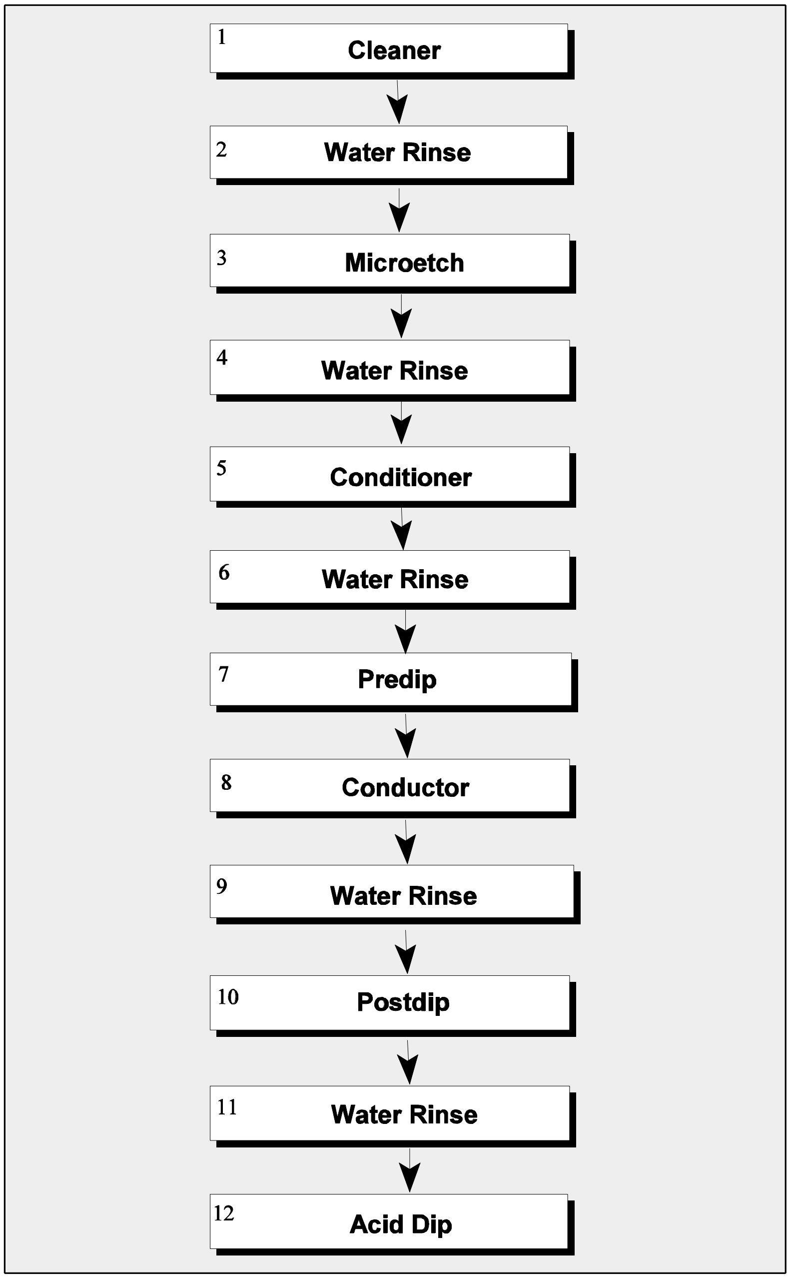
Drummed Solid or Liquid Waste (S_2). This was not reported as a spent bath treatment method for the non-formaldehyde copper facility (see Table 3.3).

Sludge Amounts From On-Site Treatment (S_3). These data are presented in Table 3.5. Reported sludge amounts for the non-formaldehyde electroless copper facility are 200 lbs/year, or 3.7 lbs per 1,000 ssf of PWB produced. Metal concentrations in sludge were not characterized.

Organic-Palladium Process

Figure 3.9 illustrates the generic organic-palladium process steps and bath sequence evaluated in the CTSA. The number and location of rinse steps shown in the figure are based on IPC Workplace Practices Questionnaire data. Thus, Figure 3.9 lists the types and sequence of baths in a generic organic-palladium line, but the types and sequence of baths in an actual line could vary. One organic-palladium facility in the IPC Workplace Practices Questionnaire database uses conveyorized equipment; the other uses non-conveyorized equipment.

Figure 3.9 Generic Organic-Palladium Process Steps and Typical Bath Sequence



Water Usage (I_3) and Wastewater (W_1). Water usage data from the questionnaire were presented in Table 3.1; wastewater generation is assumed equal to water usage. Of the two respondents using organic-palladium, one discharges directly to a stream or river following the appropriate treatment and one discharges to a POTW. In summary:

- Reported water usage for the facility using a conveyorized process is 881,000 gallons per year, or 1.8 gallons per ssf of PWB produced.
- Reported water usage for the facility using a non-conveyorized process is 7.7 million gallons per year, or 300 gallons per ssf of PWB produced.

Cleaning Chemicals (I_4). Chemicals used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire, include water, nitric acid, hydrogen peroxide, sulfuric acid, and iron chloride.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the organic-palladium process. The amount of bath chemicals used could not be quantified from the data.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined from the data. Spent bath treatment methods are presented in Table 3.3. Precipitation pretreatment was reported for conveyorized organic-palladium and pH neutralization for non-conveyorized organic-palladium processes.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). To summarize the data:

- For the organic-palladium facility using a conveyorized process, fluid circulation is reported for most of the baths and enclosure is used for vapor control for all baths.
- For the organic-palladium facility using a non-conveyorized process, panel agitation and fluid circulation are reported for most baths. Push-pull is used as a vapor control method for most baths.
- Table 3.2 lists bath surface area, volume, and bath temperature data.

Evaporation From Drying/Oven (A_2). This source of air emissions does not apply to the organic-palladium process since oven drying is not required and air drying immediately follows water rinsing.

Chemicals Incorporated Onto PWBs (P_1). Palladium is added to the board in this process.

Drummed Solid or Liquid Waste (S_2). This was not reported as a spent bath treatment method for organic-palladium processes (see Table 3.3).

Sludge Amounts From On-Site Treatment (S_3). These data are presented in Table 3.5. In summary:

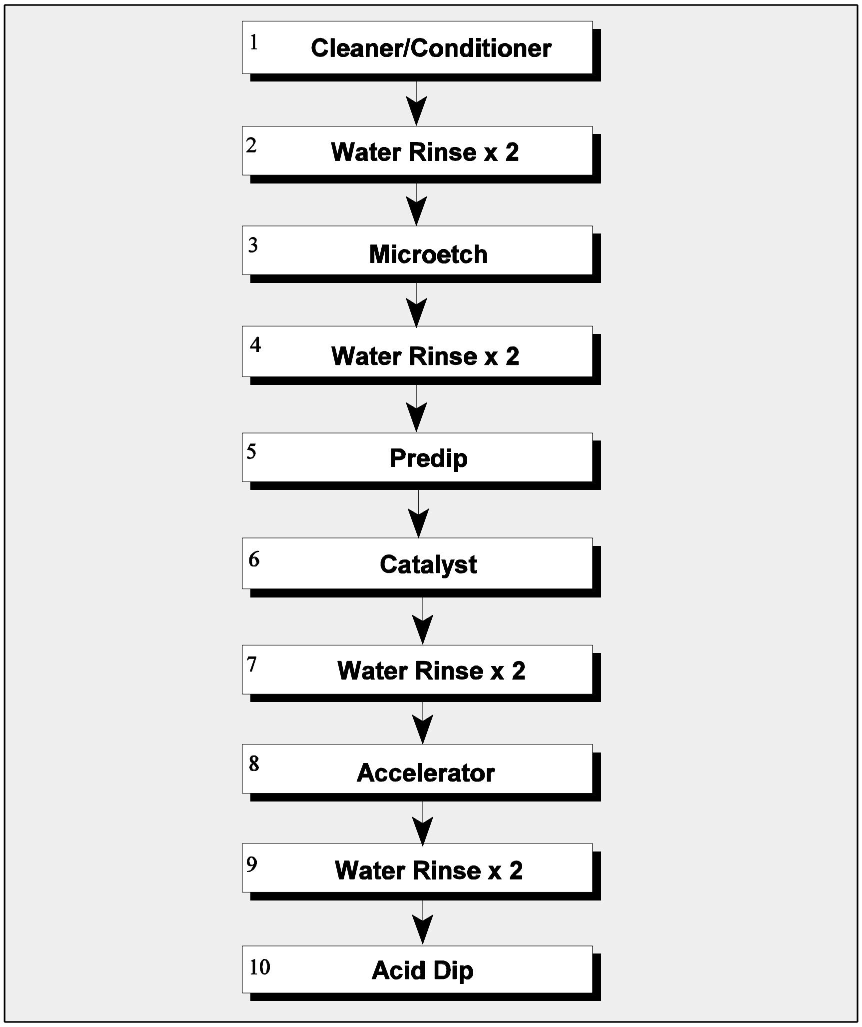
- Reported sludge amounts for the facility using a conveyorized process were 21,600 lbs/year, or 45 lbs per 1,000 ssf of PWB produced.
- Reported sludge amounts for the facility using a non-conveyorized process were 5,000 lbs/year, or 190 lbs per 1,000 ssf of PWB produced.

Metal concentrations in sludge could not be adequately characterized.

Tin-Palladium Process

Figure 3.10 illustrates the generic tin-palladium process steps and bath sequence evaluated in the CTSA. The process baths depicted in Figure 3.10 represent an integration of the various products offered within the tin-palladium technology category. The number and location of rinse steps shown in the figure are based on IPC Workplace Practices Questionnaire data. Thus, Figure 3.10 lists the types and sequence of baths in a generic tin-palladium line, but the types and sequence of baths in an actual line could vary. Thirteen tin-palladium facilities are in the IPC Workplace Practices Questionnaire database. Of these, two use conveyorized equipment and 11 use non-conveyorized.

Figure 3.10 Generic Tin-Palladium Process Steps and Typical Bath Sequence



Water Usage (I_3) and Wastewater (W_1). Water usage data from the IPC Workplace Practices Questionnaire were presented in Table 3.1; wastewater generation is assumed equal to water usage. Of respondents using tin-palladium, two discharge wastewater directly to a stream or river following the appropriate treatment while ten facilities use indirect discharge (e.g., to a POTW). (One facility did not respond to the question.) In summary:

- Reported water usage for the facilities using conveyorized processes average 912,000 gallons per year, or 0.58 gallons per ssf of PWB produced.
- Reported water usage for the facilities using non-conveyorized processes average 1.6 million gallons per year, or 7.1 gallons per ssf of PWB produced.

Cleaning Chemicals (I_4). Chemicals used for equipment cleaning, as reported in the IPC Workplace Practices Questionnaire, include water, sodium hydroxide, hydrochloric acid, and nitric acid.

Bath Chemicals Used (I_1). Appendix B presents estimated bath chemical concentrations for the tin-palladium process. The amount of bath chemicals used could not be quantified from the data.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined from the data. Spent bath treatment methods are presented in Table 3.3. Precipitation pretreatment and pH neutralization are the only reported methods for the conveyorized process and are the most commonly reported methods for the non-conveyorized tin-palladium process.

Evaporation From Baths (A_1). Air releases are modeled in the Exposure Assessment (Section 3.2). To summarize questionnaire data:

- For the conveyorized tin-palladium process, fluid circulation is reported as a mixing method for all of the baths and enclosure is used for vapor control for all baths.
- For the non-conveyorized tin-palladium processes, panel agitation is used in about 2/3 of the baths, fluid circulation in about ½ of the baths, and air sparging for 1/3 of the microetch baths. Vapor control methods include push-pull and enclosure for a few baths, and covering for about 1/3 of the baths.
- Table 3.2 lists bath surface area, volume, and bath temperature data.

Evaporation From Drying/Oven (A_2). This source of air emissions does not apply to tin-palladium processes since oven drying is not required and air drying immediately follows water rinsing.

Chemicals Incorporated Onto PWBs (P_1). Palladium and small quantities of tin are added to the board in the tin-palladium process.

Drummed Solid or Liquid Waste (S_2). This was reported as a spent bath treatment method for six out of 64 baths by the facilities with non-conveyorized tin-palladium processes (see Table 3.3). The total quantity of drummed waste was not reported.

Sludge Amounts From On-Site Treatment (S_3). Sludge data are presented in Table 3.5. In general:

- Reported sludge amounts for the conveyorized facilities average 17,000 lbs/year, or 9.5 lbs per 1,000 ssf of PWB produced.

- Reported sludge amounts for the non-conveyorized facilities average 6,700 lbs/year, or 27 lbs per 1,000 ssf of PWB produced.

Metal concentrations in sludge could not be adequately characterized.

3.1.4 Uncertainties in the Source Release Assessment

Uncertainties and variations in the data include both gaps in knowledge (uncertainty) and variability among facilities and process alternatives. These are discussed below.

For the IPC Workplace Practices Questionnaire and Performance Demonstration data:

- There may be uncertainties due to misinterpretation of a question, not answering a question that applies to that facility, or reporting inaccurate information. Also, because of a limited number of responses for the alternative processes, information more typical for that process may not be reported.
- Variation includes variation within or among process alternatives, or difference due to PWB ssf produced. Again, for MHC process alternatives with a limited number of responses, statistical summaries of the data may be precluded, and data may not be representative of most PWB facilities.

For the supplier-provided data:

- Knowledge gaps include a lack of information on proprietary chemicals, incomplete bath composition data, and the reporting of wide ranges of chemical concentrations on a MSDS rather then specific amounts in the formulations.
- Variation includes variation in bath chemistries and process specifications among suppliers for a given process alternative. The publicly-available bath chemistry data, chemical concentrations, and supplier recommendations may not apply to a specific facility due to variation in process set-up and operation procedures.

Other uncertainties pertain to the applicability and accuracy of estimates and assumptions used in this assessment.